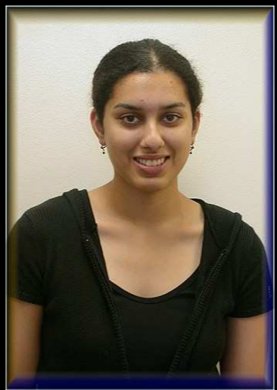
MICROFABRICATION LAB Internship 2006

UC BERKELEY
EECS

Wafer Resistance Uniformity Tests For Edwards Sputtering System



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Outline

- Our first weeks here
- Uniformity project
  - Objective
  - Theory
    - Define terms
    - The Mask we used/Split Bridge Resistors
    - Derivations of equations/ Van der Pauw relation
  - Procedure
  - Results: 4 in. wafers
  - Results: 6 in. wafers
  - Graphs/Analysis
  - Obstacles
  - Conclusions
- Acknowledgments

Our First Weeks Here

Basic Wafer Processing

- Sinks
  - Piranha Bath ($H_2SO_4 + H_20_2$)
  - DI Water Rinse (QDR)
  - Spin Dryers
- Furnaces
  - Dry Oxide vs. Wet Oxide
  - Loading and Running Recipes for Tystar furnaces
- Photolithography
  - SVG Coaters
  - Photoresist exposure and developing
- Sputtering
  - Edwards thin-film deposition
- Etching
  - Lam3 Aluminum Etching
  - Technics C Plasma Etch
- Measuring/Testing Tools
  - Nanospec
  - ASIQ
  - Linewidth measuring

Clean Room Procedures

•Clean Room attire: bunny suit, goggles, gloves booties, cap

•Hazards, safety, precautions, spill cleanup

Mask Making

•Ultratech Mask Copier

•APT Chrome Mask Process

•Exposure and development of mask patterns

Our Project

•Test a variety of conditions (applied power, wafer angle, Ar pressure) in the Edwards to optimize sputtering uniformity

•Test the uniformity of the aluminum film by testing the resistance and sheet resistance across each wafer

•Design a 6-inch mask with structures compatible with the van der Pauw principle to test for resistance and sheet resistance in the Autoprobe.

Our Project

Terms

Resistance: measured in Ω, resistance is a measurement testing opposition to the passage of electrical current. A higher resistance in an electric circuit determines that a smaller amount of current is flowing in the circuit for the voltage applied.

Ohm's Law:

$$\boxed{R = \frac{V}{I}}$$

R is the resistance of the object, usually measured in ohms
V is the potential difference across the object, usually measured in volts
I is the current passing through the object, usually measured in amperes

Sheet Resistance: Measured in Ω/□, sheet resistance is a measure of the resistivity of thin films that have a uniform thickness. Assuming a square area for sheet resistance measurement, L=W and $R_s = \frac{\rho}{t}$

$$\boxed{R = \frac{\rho}{t}\frac{L}{W} = R_s \frac{L}{W}}$$

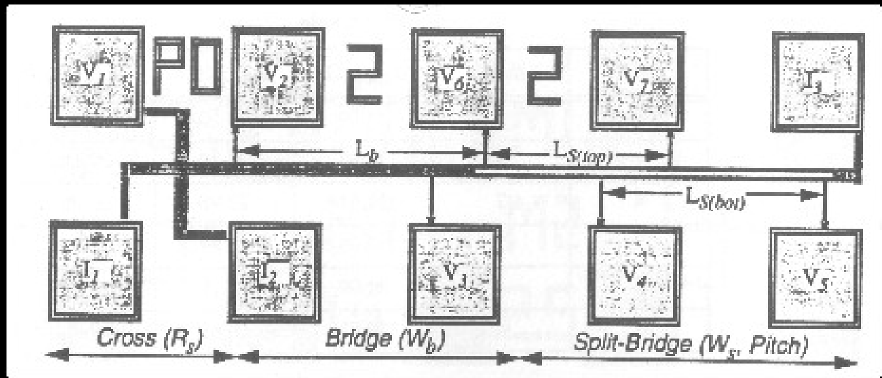
R is the resistance of the object, usually measured in ohms
ρ is the resistivity, a constant with a unique value for every electrically conducting element
t is the sheet thickness, or the thickness of the film
L is the length of the object through which the current is passed
W is the width of the object, in sheet resistance measurements (over a square area), this terms cancels out with the length

Why use resistance?
Because our project focused on optimizing film uniformity, we chose to measure resistance and sheet resistance across the wafer as a way to quantify our uniformity measurements. With the set of resistance data, we were then able to draw contour maps and visually characterize our uniformity results.

Our Project

Our Mask

•The 6 inch mask we used was originally designed as the Metal 1 layer of a far more complicated set of test structures.
•The structure we used (below) allowed for both resistance, sheet resistance, and linewidth tests and required only one mask processing step (other test structures required Metal 2 and other mask layers)

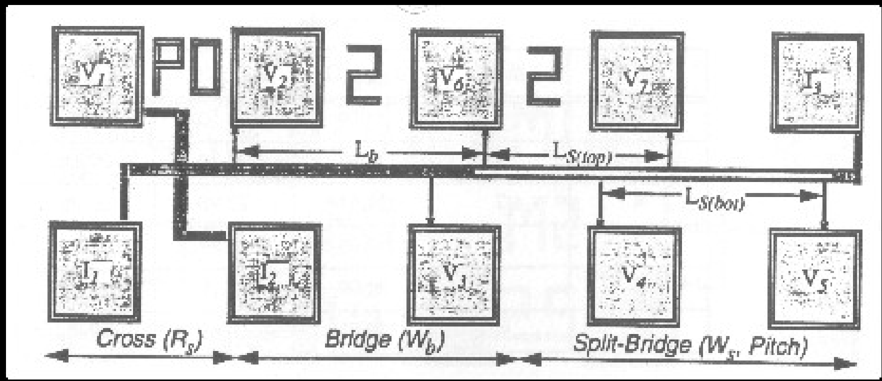


After initial thickness testing on the ASIQ, we used the Autoprobe to measure resistance, sheet resistance, and linewidth of The Split-Cross-Bridge Resistor test structure above.

•To measure **resistance**, we ran a simple test flowing current between two opposite pads and measuring the output voltage. By scripting a simple $R=\frac{V}{I}$ formula program, we were easily able to measure resistance.

Our Project

Sheet Resistance Calculations



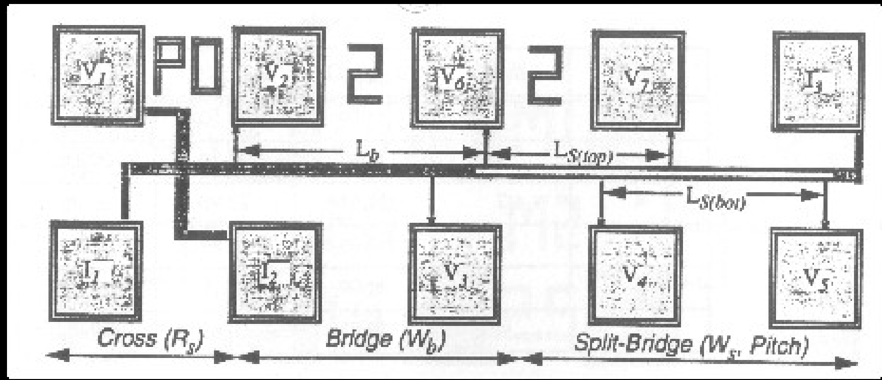
•To derive the measurements and formula for **sheet resistance**, we used the van der Pauw relation, establishing that

$$R_s = \frac{\pi}{\ln 2}\,\frac{V_1 - V_2}{I_{R_s}}$$

where $\frac{\pi}{\ln 2}$ is the geometric conversion factor for this specific structure. Based on the basic formula for resistance $R = \frac{V}{I}$, we can establish this sheet resistance equation by flowing current through the 4 pads surrounding the cross resistor in an alternating pattern according to the van der Pauw relation. The geometric conversion factor $\frac{\pi}{\ln 2}$ is calculated to account for the specific geometry of this structure.

Our Project

Line width Calculations



•To derive the formula for **line width** measurement, we combined our sheet resistance data with the original Resistance formulas:

$$R_s = \frac{\rho}{t} \qquad R = \frac{V}{I}$$

$$R = \rho \frac{L}{Wt} \longrightarrow R = R_s \frac{L}{W} \longrightarrow W = \frac{R_s L}{R} \longrightarrow W = R_s L \frac{I}{V} =$$

$$\boxed{\mathbf{W_b = \frac{R_S L_b I_b}{V_b}}}$$

Procedure

- Grow 300 A of oxide on wafers
  - Tystar furnaces
  - Wet oxide vs. Dry oxide
- Sputter aluminum layer (3000 A)
  - Edwards
  - Variables: Ar pressure, applied power, wafer angle
- Spin photoresist
  - SVG Coat6
- Expose photoresist
  - Expose photoresist to our 6 inch mask: photolithography
  - GCA 8500 Wafer Stepper
- Develop the wafers
  - SVG Coat6
- UV bake/Hard bake
  - UV Bake: hardens photoresist before etching, decreases etch rate of remaining photoresist
- Aluminum Etch Wafers
  - Lam3
  - Remove aluminum from developed photoresist pattern
  - Remaining aluminum layer completes the Metal1 mask layer
- Remove remaining photoresist
  - Matrix: oxygen plasma reacts with remaining organic compounds on the wafer (photoresist)
- Testing
  - Aluminum Thickness
    - ASIQ
  - Resistance
    - Autoprobe Testing
      - Sheet Resistance, Line Width, Wafer thickness uniformity

Tystar Furnaces: Oxide Growth

Dry Oxide

• Furnaces heated to very high temperatures
• Pure oxygen gas is pumped into the chamber
• Oxygen gas reacts with silicon on the surface of the wafer, slowly oxidizing the surface
• Much slower process (deposition of even a very thin film takes hours)
• Oxide produced is much better quality, purer
•Our first two batches of wafers were coated with 300A of dry oxide for better film quality

Wet Oxide

• Can grow oxide at much lower temperatures
•A mixture of O_2 gas, (H_2 gas), and water vapor is pumped into the chamber
• The oxygen gas and water vapor react with the silicon surface of the wafer, oxidizing the surface
• Because of the water vapor (“wet” oxide), the deposition rate is much faster (a thin layer can take 10 or 15 minutes vs. a few hours)
•Oxide produced is of poorer quality, less pure
•Our final batch of 6 inch wafers was coated with wet oxide to expedite the procedure time

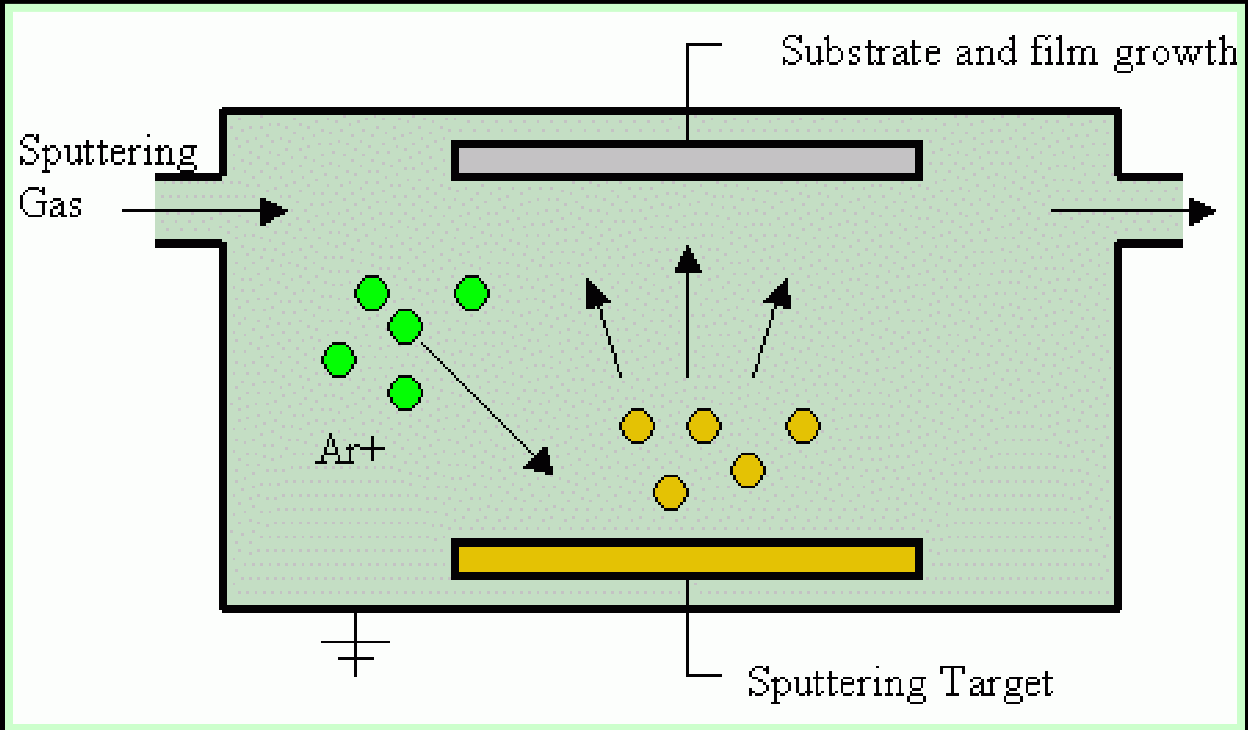
Edwards Sputtering

Sputtering:

•Used for thin-film deposition

•Atoms from a solid target are struck and displaced by high-energy plasma ions, releasing them into the gas phase

•Displaced target atoms coat all exposed faces of the chamber, including depositing a thin film on the exposed surface of the wafer

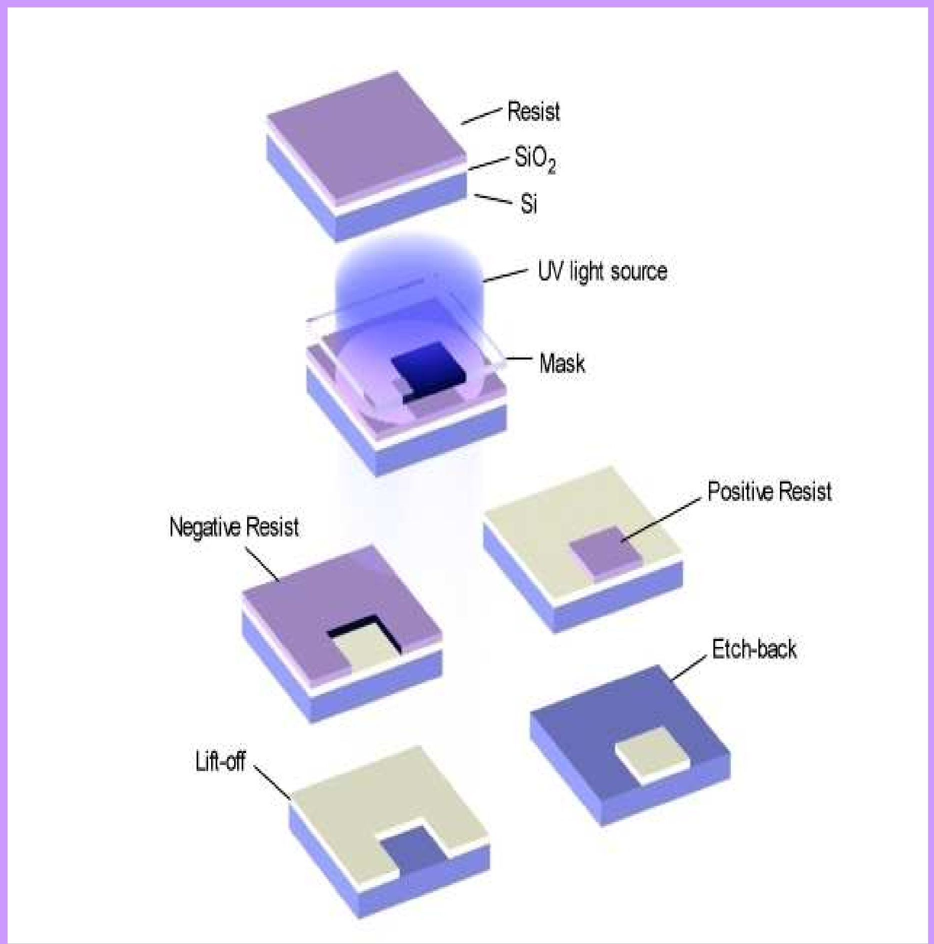


Edwards Sputtering

Our Procedure

1. Put in aluminum target
2. Pump down chamber to 1x 10^{-5} Torr.
3. Pump in Ar gas
   - We used the pressure of Ar gas as a variable for this experiment
   - We set the pressure alternately at 5, 10, and 15 mTorr (at 300 W constant power)
4. Turn on DC power supply to strike plasma
   - This was another variable in our experiment
   - While the Ar pressure remained at constant pressure (5 mTorr), we varied the power between 150, 300, and 450 watts
5. Plasma ions strike target displacing aluminum atoms, coating the silicon wafer
6. Deposit 3000 A of aluminum on the surface of the wafer (between 10 and 15 minutes of sputtering)

Photolithography: Exposing and Developing Photoresist



SVG Coat 6:

~ Spins 1.2 microns of I line photoresist.

~ Soft bake for 60 sec. at 90°C.

GCA 8500 Wafer Stepper

~ Exposes/ patterns wafers under UV light, stepping the mask pattern across the wafer.

SVG Coat 6:

~ Develops exposed photoresist on regions of the wafer that were exposed to UV light.

~Leaves unexposed photoresist behind on the wafer as a protective coating against etchants.

Aluminum Etching

- UV Bake
  - Before etching, we hard baked our wafers, strengthening the remaining photoresist
  - By hardening the unexposed photoresist before etching, we decrease the etch rate into the protective photoresist layer and decrease the possibility of etching through the photoresist into the aluminum layer below

- Lam 3 Aluminum Etch
  - uses gas atoms generated by plasma to remove the thin aluminum film on the wafers
  - Unexposed regions of the wafer are protected by a remaining layer of photoresist
  - Lam3 etches into both aluminum and photoresist, but will etch aluminum films at a much faster rate. Assuming a thick enough coat of photoresist is left behind in unexposed regions, the photoresist will prevent the underlying aluminum layer from being etched
  - After etch, only regions protected by photoresist will have aluminum remaining, connecting various devices patterned/designated by the mask

- Matrix
  - Uses an oxygen plasma to remove all remaining photoresist
  - Oxygen plasma atoms do not effect the aluminum or silicon layers, but will erode organic compounds only (removing any organic impurities and the remaining photoresist)

Testing

Aluminum Thickness Test

- Alpha Step IQ Surface Analyzer (ASIQ)
  - ✓Uses a needle to probe the surface of each wafer, measuring the height of the aluminum walls post-etch
  - ✓Gives us the original aluminum sputtering thickness, assuming aluminum was completely etched.

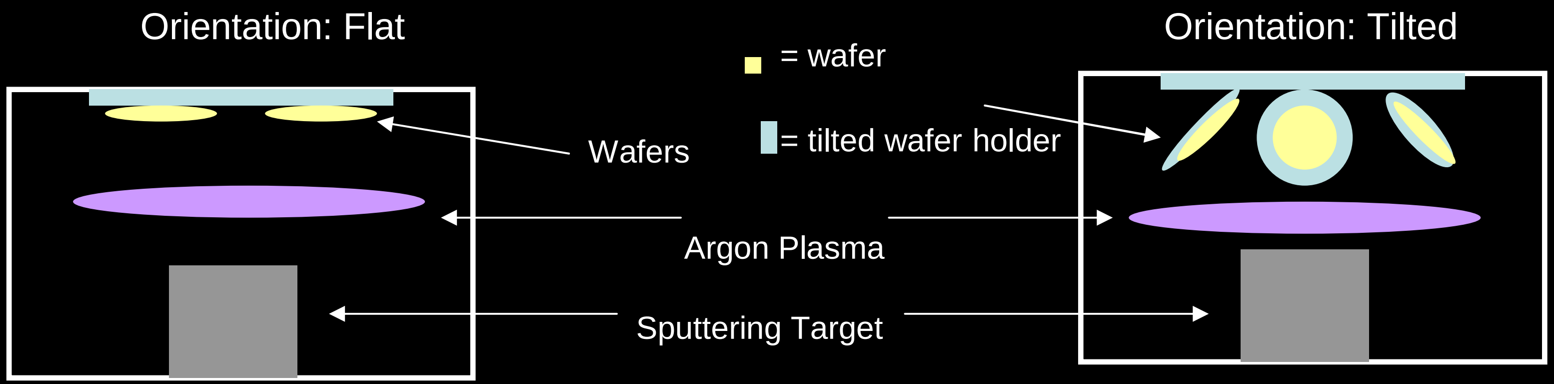
Resistance Tests

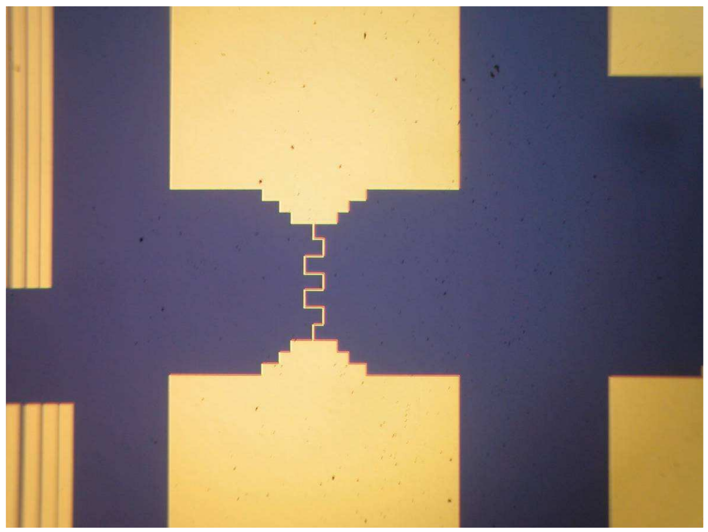
- Four Point Probe Resistivity Measurement
  - ✓Because the mask we used for the 4 in. wafers was not compatible with the Autoprobe, we measured a series of resistors on each die by hand
  - ✓Using 2 needle probes, we ran current through each resistor, measuring resistance across the wafer and ultimately creating a contour map of film thickness

- Autoprobe Testing (6 in. wafers only)
  - ✓Using the Split-Cross-Bridge-Resistor described earlier, we used the Autoprobe to test linewidth, resistance, and sheet resistance across each wafer.
  - ✓With the data, we were able to create contour maps for each wafer of film thickness, comparing to those we created with the 4 in. wafers

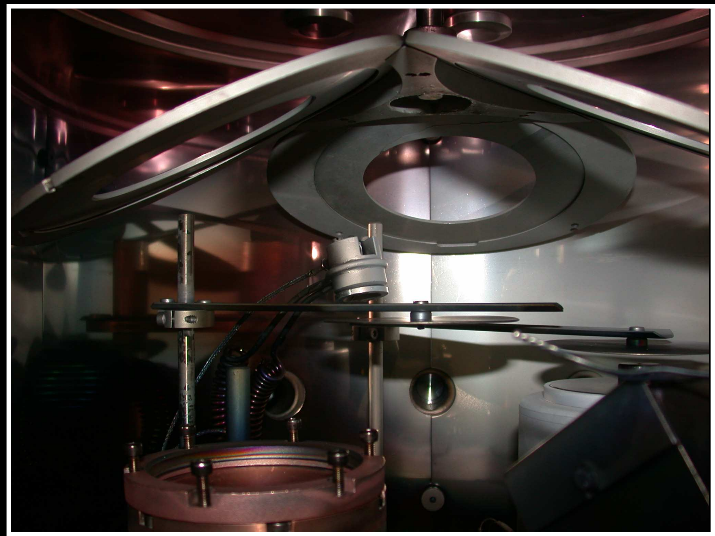
Results

4 Inch Wafer Testing





This is the structure we used to measure resistance in our 4 inch wafer testing



A picture of the tilted orientation of the wafer holders inside the Edwards sputterer

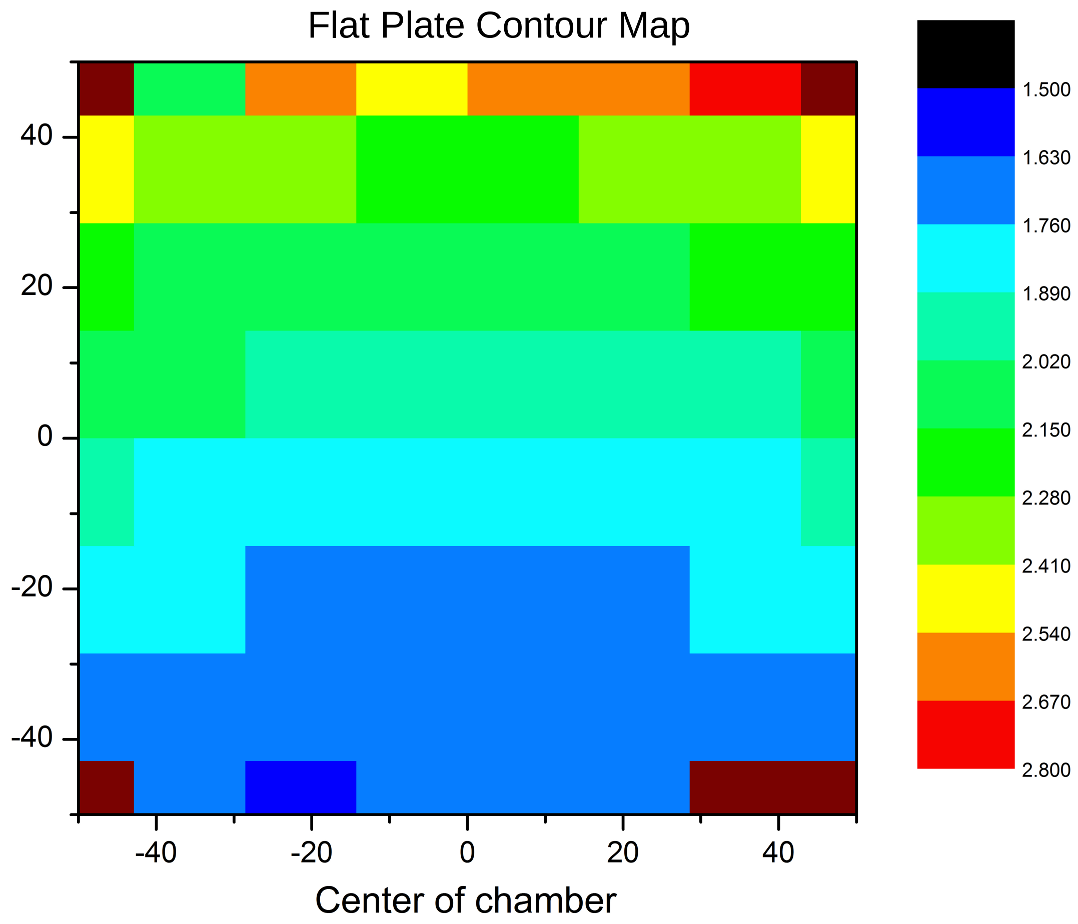
Results

4 Inch Wafer Testing

Resistance Analysis

Higher Resistance

Thinner Film



Lower Resistance

Thicker Film

•The relationship between these resistance results and the thickeness of our film is one-to-one

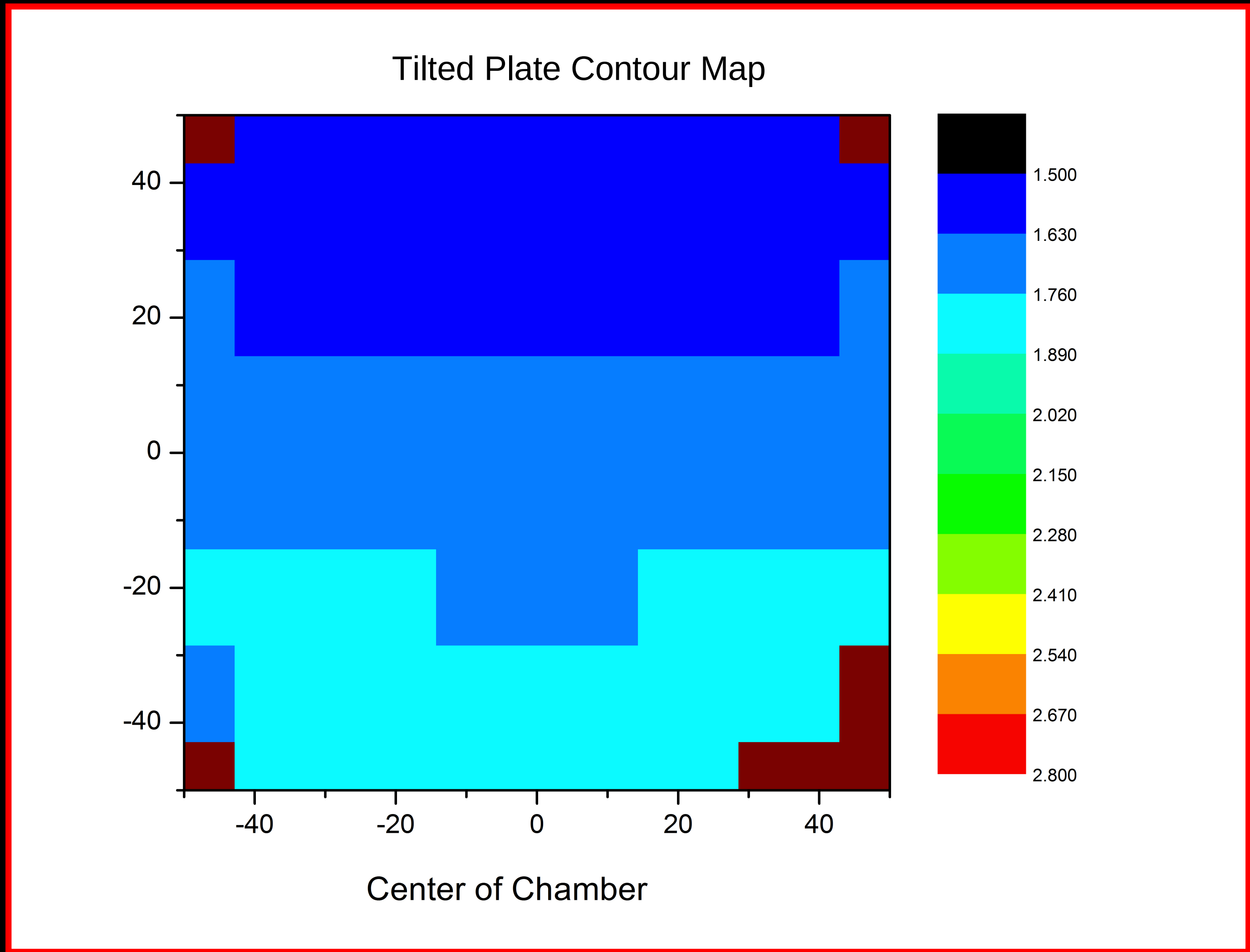
Results

4 Inch Wafer Testing

Resistance Analysis

Lower Resistance

Thicker Film



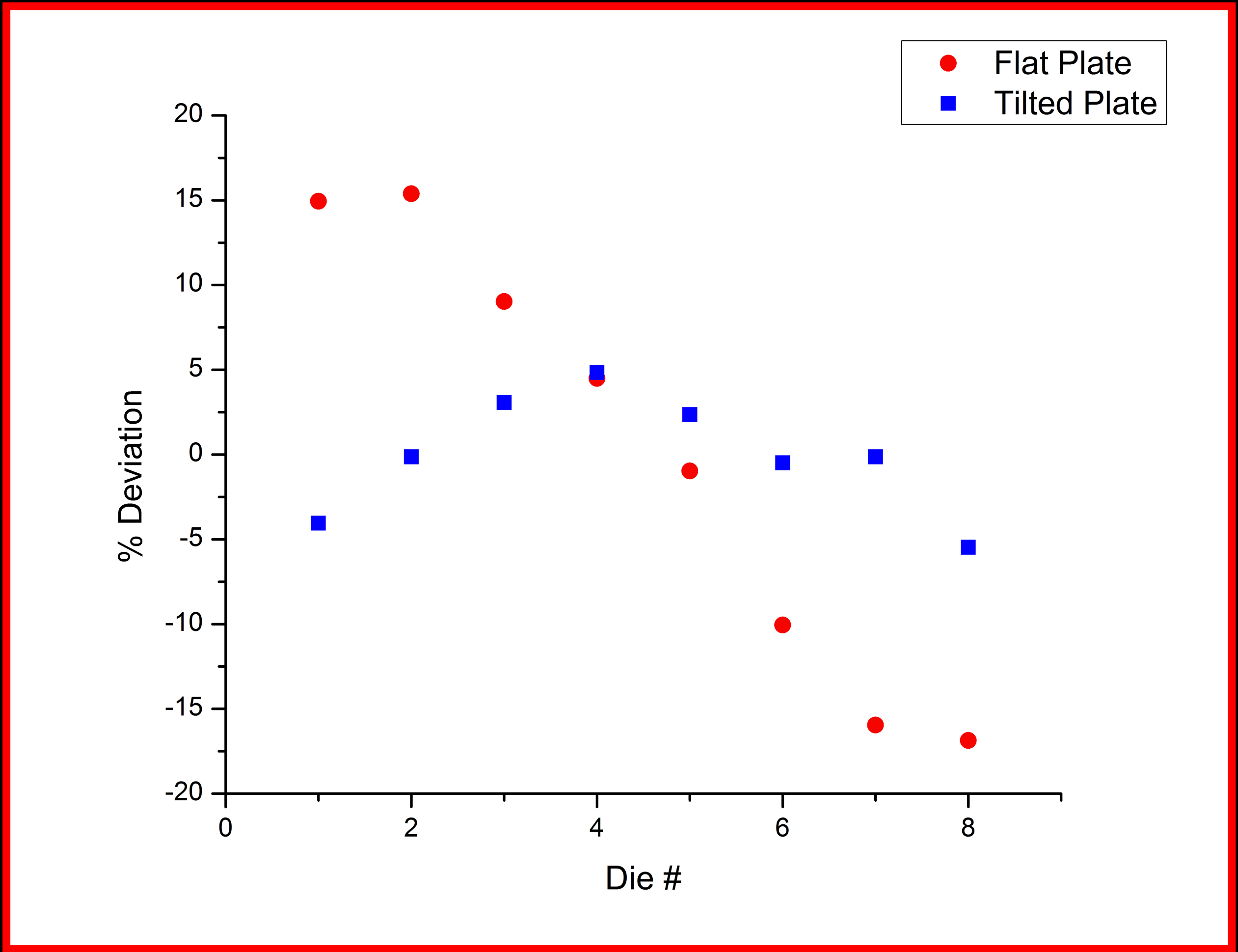
Higher Resistance

Thinner Film

•Gradient is much less severe: more uniform film

Results

4 Inch Wafer Testing



Conclusions:

•% deviation is much less for the tilted plate compared with the flat plate

•Wide variation from average resistance along the edge of the flat plate (die 1 and 8)

✓Suggests extreme gradient and non-uniform thickness

•Tilted Plate gives a more uniform film than the flat plate

Results

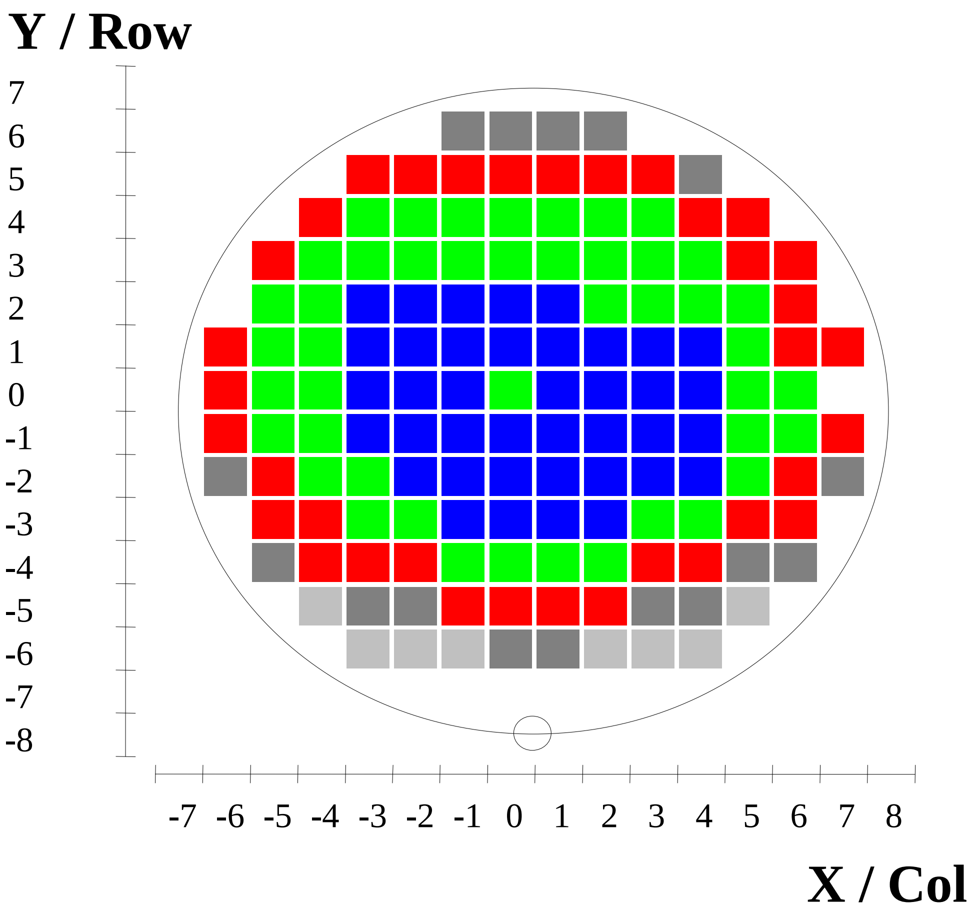
6 Inch Wafer Testing

	Deposition				Sheet resistance	
Label	Pressure	Power	time	plate	mean	SD
Edwards 1-1	4.8	300	12	tilted	0.0434	0.00443
Edwards 1-2	4.6	300	12	flat	0.0237	0.00636
Edwards 2-3	5	150	30	tilted	0.0493	0.00612
Edwards 2-4	5	150	30	tilted	0.0487	0.00547
Edwards 2-7	10	300	20	tilted	0.0433	0.00688
Edwards 2-8	10	300	20	tilted	0.0454	0.008
Edwards 2-9	15	300	30	tilted	0.0385	0.0079
Edwards 2-10	15	300	30	tilted	0.0369	0.00696

Results

6 Inch Wafer Testing

Edwards 1-1: Sheet Resistance Analysis



Statistics

Minimum: 0.0312263
Maximum: 0.0506659
Mean: 0.0434161
Sigma: 0.00442763
Samples: 143

One bin size corresponds to 1 standard deviation

Metrics Miner

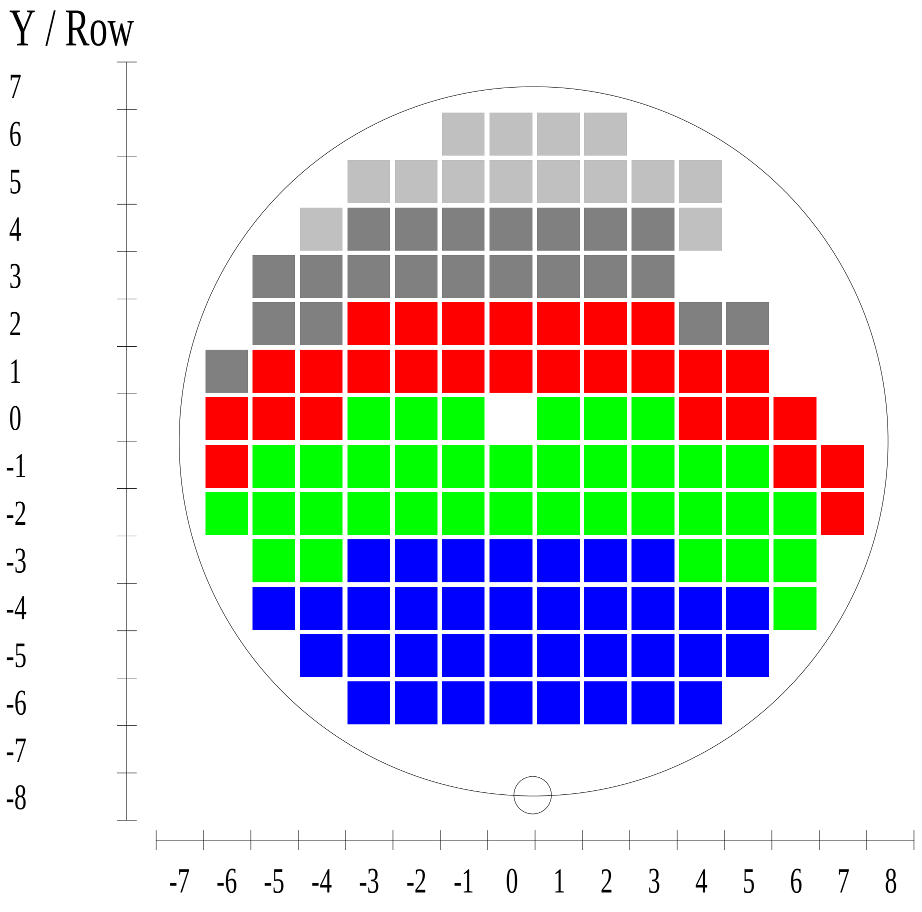
Date: 08/10/06
Time: 21:59:56

Edwards 1-1: Pressure: 4.76 mTorr Power: 300W Time: 12min Tilted Plate

Results

6 Inch Wafer Testing

Edwards 1-2: Sheet Resistance Analysis



Statistics

Minimum: 0.00973569
Maximum: 0.0333796
Mean: 0.0237535
Sigma: 0.00636488
Samples: 135

One bin size corresponds to 1 standard deviation

Metrics Miner

Date: 08/10/06

Edwards 1-2: Pressure: 4.57 mTorr Power: 300W Time: 12min Flat Plate

Results

6 Inch Wafer Testing

Edwards 2-4: Sheet Resistance Analysis

RS Analysis

- Bin 1 0.0322837 <= VAL < 0.0375081
- Bin 2 0.0375081 <= VAL < 0.0427325
- Bin 3 0.0427325 <= VAL < 0.047957
- Bin 4 0.047957 <= VAL < 0.0531814
- Bin 5 0.0531814 <= VAL < 0.0584058

This is an example of one of the wafers with a contaminated film. The blank spots in this wafer map indicate incomplete or invalid data points

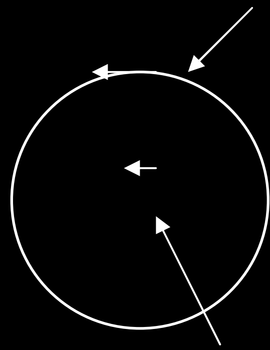
Edwards 2-4: Pressure: 5 mTorr Power: 150W Time: 30min Tilted Plate

Obstacles

Machine Failures and Delays

- Sputtering System went down for a few weeks due to a vacuum pump failure, delaying the start of our project
- There was a delay in the processing/creation of our 6-inch mask, delaying our sheet resistance results
  - Because of this delay, we started our first batch of wafers using a different 4 inch mask, individually testing resistance in the 4 Point Probe Resistivity Measure
- SVG Coat 6 did not coat wafers evenly with photoresist or developer, affecting uniformity of the photolithography process
- UV bake lamp failure
- G CAW Stepper broke down, delaying the photolithography exposure process
- Overexposure in the Lam3 etched all the aluminum off our wafers, destroying our first batch of results
- Initial programming errors and broken probe card on our first attempts to use the Autoprobe
- Our second batch of 6 inch wafers were contaminated in the Edwards, causing pits in the surface of some of our wafers (developed upon heating). We lost results for Wafers 2-1, 2-2, 2-5, and 2-6 to this problem. This also caused an unusually high standard deviation on all of our 6-inch results due to oxidation contamination

Conclusions



- We found that the tilted orientation of the wafers provides for better uniformity than the flat orientation
  - balance between 2 conditions affecting film thickness:
    - ✓Distance of wafer from target
    - ✓Tangential speed: circumference of a circle/outer edge of wafers travel faster through the plasma than the inner edge.
- Aluminum films grown in the sputtering chamber are very poor quality
- We can measure thickness uniformity by doing a simple sheet resistance test
- The Edwards has great potential as a general sputtering tool for the lab
- We were not able to conclude anything about the pressure or power dependency of film uniformity because of the poor quality of the film and contamination we encountered in our second batch of 6 inch wafers

Acknowledgements

Thank you to those who guided us through the lab our first few weeks, sacrificing your time to explain each tool's objective and role in the fabrication process.

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